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THE SUN.

"IT is because the secrets of the Sun," says Mr. Lockyer, "include the cipher in which the light messages from external Nature in all its vastness are written, that those interested in the 'new learning,' as the chemistry of space may certainly be considered, are anxious to get at and possess them." But even more significant to dwellers on the Earth are the heat radiations of the Sun, because they are determinant in all animal and vegetable life, and are the original source of nearly every form of terrestrial energy recognized by mankind. Through the action of the solar heat-rays the forests of palæozoic ages were enabled to wrest carbon from the atmosphere and store it in forms afterward converted by Nature's chemistry into peat and coal; through processes incompletely understood, the varying forms of vegetable life are empowered to conserve, from air and soil, nitrogen and other substances suitable for and essential to the life maintenance of animal creatures. Breezes operant in the production of rain and in keeping the air from hurtful contamination; the energy of water, in stream and dam and fall; trade winds facilitating commerce between the continents; oceanic currents modifiying coast climates (and no less the tornado, the waterspout, the typhoon, and other manifestations of natural forces, excepting earthquakes, frequently destructive to the works of man), all are traceable primarily to the heating power of the Sun's rays acting upon those readily movable substances of which the Earth's exterior is in part composed.

The Sun, cosmically speaking, is simply a star, but the nearest fixed star is 275,000 times more remote; so that the Sun's vastly greater brightness is, for the most part, due to mere proximity. Still, the distance of the Sun is by no means easy to conceive or

illustrate. Recalling that the distance round the Earth's equator is about 24,000 miles, ten times this gives the distance of the Moon, which is practically inconceivable; but the Sun is 390 times more remote. As the two bodies are about the same in apparent size, it follows that the Sun's actual diameter is about 390 (accurately 400) times greater than the Moon's.

The available methods of ascertaining the Sun's distance, more than a dozen in number, may be divided into three classes: (1) by geometry or trigonometry; (2) by gravitational effects of Sun, Moon and planets; (3) by the velocity of transmission of light. The first includes transits of Venus, and near approaches of the Earth to Mars, or to small planets exterior thereto, at which times the distances of these bodies from the Earth are not difficult to measure. Adopting, with Professor Young, the number 100 as indicating a method which would insure absolute accuracy, this class of determinations will range all the way from 20 to 90. The second class of methods, too mathematical for explanation here, depends on the Earth's mass, and their present value may be expressed as 40 to 70; but the peculiar nature of one of them (utilizing the disturbances which the Earth produces in the motion of Venus and Mars) offers an accuracy continually increasing, so that 200 years hence it alone will have settled the Sun's distance with a precision entitled to the number 95. But the best methods now available are embraced in the third class, which employ the velocity of light (determined by actual physical experiment), and their present worth is about 80 or 90. The problem of the Sun's distance is one of the noblest ever grappled by the mind of man; and no one of the numerous elements with which it is complexly interwoven can yet be said to have been determined with the highest attainable precision.

An admirable summary of investigation of the Sun's distance is given by Dr. Gill as an introduction to Mrs. Gill's *Six Months in Ascension* (London, 1880), an account of an expedition to that island three years previously. The value of the Sun's parallax, $8''.848 \pm 0''.013$, determined by Professor Newcomb (*Washington Observations*, 1865), and now become classic, is adopted in all the national astronomical ephemerides except the French, which adheres to a larger value of Le Verrier. Independent determinations of this constant below given show the measure of modern precision in this important field of research; and the relations of the values to each other will be apparent on recalling that the addition of $0''.01$ to the Sun's parallax is equivalent to diminishing his distance about 105,000 miles:

		$''$ $''$
(1880) TODD	Velocity of Light	8.808 ± 0.006
(1881) PUISEUX	Contact and Micrometer Observations, Transit of Venus, 1874	8.8
(1881) TODD	American Photographs, Transit of Venus, 1874	8.883 ± 0.034
(1885) NEWCOMB	Velocity of Light	8.794
(1885) OBRECHT	French Photographs, Transit of Venus, 1874	8.81 ± 0.06
(1887) CRULS	Brazilian Observations, Transit of Venus, 1882	8.808
(1887) E. J. STONE	British Contact-Observations, Transit of Venus, 1882	8.832 ± 0.024
(1888) HARKNESS	American Photographs Transit of Venus, 1882	8.842 ± 0.012
(1889) HARKNESS	Planetary Masses	8.795 ± 0.016
(1890) BATTERMANN	Lunar Occultations	8.794 ± 0.016
(1890) NEWCOMB	Re-discussion Transits of Venus, 1761 and 1769	8.79 ± 0.034
(1892) AUWERS	German Heliometer Observations, Transits of Venus, 1874 and 1882	8.880 ± 0.022
(1892) GILL	Opposition of Small Planets (12) Victoria	8.809
(1893) GILL	Opposition of Small Planets (80) Sappho	8.811
(1894) GILL & ELKIN	Opposition of Small Planets (7) Iris	8.825 ± 0.008

Also several other values of this important constant have been derived, and there is an increasing tendency to cluster round the figure $8''.81$.

Professor Harkness published in 1891 a laborious paper entitled *The Solar Parallax and its Related Constants* (Washington Observations, 1885), in which this quantity is treated, not as an independent constant, but as "entangled with the lunar parallax, the

constants of precession and nutation, the parallactic inequality of the Moon, the lunar inequality of the Earth, the masses of the Earth and Moon, the ratio of the solar and lunar tides, the constant of aberration, the velocity of light and the light-equation." Collating the great mass of astronomical, geodetic, gravitational and tidal results which have been accumulating for the past two centuries and applying the mathematical process known as a 'least square adjustment,' he derives the value $8''.809 \pm 0''.006$, giving for the mean distance between the centres of Sun and Earth, 92,797,000 miles. A valuable bibliography of the entire subject concludes Professor Harkness's paper.

Professor Newcomb, in his *Elements of the Four Inner Planets and the Fundamental Constants of Astronomy* (Washington, 1895), on which his new tables of the principal planets of the solar system are founded, derives from his discussion of all existing data a definitive value for the Sun's parallax equal to $8''.790$. This important paper is a supplement to the *American Ephemeris* for 1897.

Possible changes of the Sun's diameter from time to time have been critically investigated by Dr. Auwers, of Berlin, and Professor Newcomb, with negative results; nor are the observations yet made sufficient to disclose any difference between equatorial and polar diameters. The heliometer affords the best means of measuring the Sun's apparent diameter or the angle subtended by its disk. The orbit of the Earth being elliptical, this diameter changes in the inverse proportion of the Earth's varying distance from the Sun; at the beginning of the year it is $32' \, 32''$ and $31' \, 28''$ early in July, the mean value being $32' \, 0''$. Supposing the form of the Earth's orbit unknown, daily measures of the Sun's varying diameter would alone, in the course of a year, enable the precise determination of the figure of the orbit, so accurately can these measures now be made. When at its mean distance from the Earth, the linear equivalent of one second of arc at the Sun is 450 miles. The present uncertainty in the solar diameter does not much exceed $2''$; that is to say about 900 miles, or quite approximately $\frac{1}{1000}$ of the entire diameter. Dr. Auwers's recent value of the semi-diameter is $15' \, 59''.63$; and if we take the mean distance of the Sun at 93,000,000 miles, this numerical relation gives the Sun's diameter 865,350 miles.

A simple relation between the Sun's mass and its dimensions relatively to the Earth enables us to determine that the force of gravity at the Sun's surface is $27\frac{2}{3}$ times greater than it is here; so that while a body on the Earth falls only 16.1 feet in the first second of time, at the Sun its fall in a corresponding interval would be no less than 444 feet. If a hall clock were transported to the Sun, its leisurely pendulum would vibrate more than five times as rapidly. So great is the Sun's mass that a body falling freely toward it from a distance indefinitely great would, on reaching the Sun, have acquired a velocity of 383 miles per second. The great Krupp gun exhibited at the World's Fair in 1893, if fired from Chamounix in the direction of Mont Blanc, at an elevation of 44°, would propel its projectile of 475 pounds in a curve meeting the earth at Pre-Saint-Didier, $12\frac{1}{2}$ miles from Chamounix, and whose highest point would be more than a mile above the summit of Mont Blanc. If we could suppose the same gun to be fired similarly on the Sun, so great is the force of gravity there that the projectile would be brought down to rest about half a mile from the muzzle.

From groups of the faculæ, Dr. Wilsing has found that the Sun's equator revolves in $25^d.23$; but these observations are exceedingly difficult, and a repetition of the work is desirable. Professor Young and Dr. Crew have determined the period of rotation of the Sun's equator by means of the

spectroscope, utilizing that technicality called Doppler's principle. This means that the spectra from opposite sides of the Sun (the east side coming toward the Earth, and the west receding from us) are optically brought alongside each other; then careful measurement of the amount of divergence of a given line in the two spectra forms the basis for calculating the rapidity of rotation. M. Duner, of Lund, Sweden, carrying this research still farther, into high solar latitudes, finds for the equatorial regions a period of sidereal rotation equal to $25^d.46$, in close correspondence with the determinations of Carrington and Spoerer from the spots alone; while the slowing down as the poles are approached is remarkably verified; for his results give, for the rotation period at latitude 75°, no less than $38^d.54$. M. Duner's observations were made near the time of minimum spots, and it would be interesting to repeat the determination near the epoch of maximum spottedness.

The Sun's axis is inclined 83° to the plane of the Earth's orbit; and if prolonged northward to the celestial sphere, the axis would intersect it near the third magnitude star δ Draconis, so that in March the Sun's north pole is turned farthest from the Earth, in September it is inclined 7° toward us. Spectroscopic study of the sun-spots shows that their inferior brilliance is due in part to a greater selective absorption than obtains in the photosphere generally. Continuous and systematic records of the solar spots are now kept at Greenwich (in connection with Dehra Dun, India), at Potsdam near Berlin, at Chicago, and elsewhere. Exceedingly fine photographs of sun-spots and the solar surface have been obtained at Potsdam (*Himmel und Erde*, ii., 1890, 24).

Also at Meudon, Paris, M. Janssen has had extraordinary success in photographing the Sun's surface in detail, and the granulation is very sharply defined in his originals. In viewing the Sun with a telescope this granulation can be satisfactorily seen with a magnifying power of about 400 or 500, under good atmospheric conditions.

While the 42 years' faithful work of Schwabe, as revised by Wolf and collated with other and scattering results, gives an average sun-spot period of $11\frac{1}{9}$ years, there are great irregularities. During the latter half of the 17th century, the ordinary progress of the spot cycle appears to have intermitted; the intervals between maxima have varied from 8 to $15\frac{1}{2}$ years, and between minima from 9 to 14 years. True interpretation of this indicates with an approach to certainty that the cause of the periodicity does not lie in planetary or any exterior agency, but that it is seated in the Sun itself.

The solar prominences, or hydrogen flames, are drawn in full sun-light, by means of a spectroscope adjusted delicately on the edge of the Sun, this instrument reducing the sky-glare, without dispersing very much the light of the prominence itself. This method has now been in common use more than a quarter century. But by means of the spectro-heliograph devised by Professor Hale, of the University of Chicago, the hindering effects of our atmosphere are in greater part evaded; and he is enabled to secure on a single plate (with single exposure) not only the photosphere and sun-spots, but the chromosphere and protuberances. Also the same instrument (which utilizes monochromatic light, or light of a single color only) has demonstrated that the faculæ, which to the eye are ordinarily seen only near the Sun's limb, actually extend all the way across the disk of the Sun, in approximately the regions of greatest spot-frequency. Professor Hale's progressive methods of solar research will soon give us large accumulations of facular observations, from which the

laws of their appearance may be finally determined, and their connection with the formation of spots and prominences satisfactorily made out. Similar results from the work of M. Deslandres, of the Paris Observatory, are given in Mr. Maunder's paper in *Knowledge*, for January, 1895.

Both spots and prominences have a well recognized variation in heliographic or solar latitude; the former has been investigated by Dr. Spoerer of Potsdam, and the latter by M. Riccò of Palermo. Just before the epoch of a minimum (1888, for example) the spots are seen nearest the Sun's equator; coincidently with the minimum these circum-equatorial spots cease, and a series breaks out afresh in high solar latitudes. Thenceforward to the time of the next minimum the mean latitude of the spots tends to decline continuously. This fluctuation is called 'the law of zones.' Dr. Spoerer's investigations further show an occasional predominence of spots in the Sun's southern hemisphere not counterbalanced by a corresponding appearance in the northern. Also, during the last half of the seventeenth century and the early years of the eighteenth, there seems to have been a remarkable interruption of the ordinary course of the spot cycle, and the law of zones, too, was apparently in abeyance. The latitude variations of the prominences follow quite closely the fluctuations of the spots, although exhibiting a greater divergence between the Sun's two hemispheres than the spots do.

Independently of his light and heat, the Sun's supreme right to rule his family of planets is at once apparent from his superior size, and from his vastly greater mass. Relative weights of common things readily give a notion sufficiently precise: let the ordinary bronze cent represent the weight of the Earth; Mercury and Mars, then, the smallest planets, would, if merged in one, equal an old-fashioned silver three-cent piece; Venus, a silver dime; Uranus, a gold double-eagle and a silver half-dollar (or, what is about the same thing in weight, a silver dollar, half dollar, and a quarter dollar taken together); Neptune, two silver dollars; Saturn, eleven silver dollars; Jupiter, rather more than two pounds avoirdupois (37 silver dollars); while the sun, outweighing 750 times all the planets taken together, would somewhat exceed the weight of the long ton.

As the Sun shines with inconceivably greater power than any terrestrial source, an idea of its total light is difficult to convey intelligibly in terms of the ordinary standards adopted by physicists. Its intrinsic brightness, or amount of light per square unit of luminous surface, exceeds the glowing carbon of the electric arc light about $3\frac{1}{2}$ times, or the glowing lime of the calcium light about 150 times. "Even the darkest part of a sun-spot outshines the lime light" (Young). Some rude notion of the total quantity of light received from the Sun is perhaps obtainable on comparison with the average full moon, whose radiance the Sun exceeds 600,000 times. In consequence of absorption of the Sun's light by its own atmosphere, the Earth receives very much less than it otherwise would; while if the absorbing property of the atmosphere were entirely removed, the Sun would (according to Professor Langley) shine two or three times brighter, with a color decidedly blue, resembling the electric arc. As a further effect of this absorption, the intrinsic brightness at the edge is $\frac{2}{5}$ that of the centre of the disk (according to Professor Pickering); and Dr. Vogel makes the actinic or photographic intensity only $\frac{1}{7}$ for the same region. While this shading off towards the edge is at once apparent to the eye, when the entire Sun is projected on a screen, the rapid actinic gradation is more marked in photographs of the Sun, which strongly show the effect of under-exposure near the

limb, if the central regions of the disk have been rightly timed.

Kirchhoff in 1858 formulated the following principles of spectrum analysis: (1) Solid and liquid bodies (also gases under high pressure) give, when incandescent, a continuous spectrum; (2) gases under low pressure give a discontinuous but characteristic bright-line spectrum; (3) when white light passes through a gas, this medium absorbs rays of identical wave-length with those composing its own bright-line spectrum. These principles fully account for the discontinuous spectrum of the Sun, crossed, as it is, by the multitude of Fraunhofer lines. But it must be observed that the relative position of these lines will vary with the nature of the spectroscope used; with a prism spectroscope the relative dispersion in different parts of the spectrum varies with the material of the prism; with a grating spectroscope (in which the dispersion is produced by reflection from a gitter or grating, ruled upon polished speculum metal with many thousand lines to the inch), the dispersion is wholly independent of the material of the gitters, and it is called, therefore, the normal solar spectrum. Compared with this a prismatic spectrum has the red end unduly compressed, and the violet end as unduly expanded.

Rutherfurd, assisted by Chapman, ruled excellent gratings mechanically; but the last degree of success has been attained by Professor Rowland, of Baltimore, whose ruling engine covers specular surfaces, either plane or concave, six inches in diameter with accurate lines, up to 20,000 to the inch. The concavity of the gratings vastly simplifies the accessories of the spectroscope for researches in which they are applicable. So great is the dispersion obtainable that the solar spectrum, as photographed by Rowland with one of these gratings and enlarged three-fold, is about forty feet in length. The superiority of his ruling engine consists primarily in the accurate construction and perfect mounting of the screw, which has 20 threads to the inch, and is a solid cylinder of steel, about 15 inches long and $1\frac{1}{8}$ inches in diameter. (Article 'Screw,' *Encyclopædia Britannica*, 9th edition.) The perfect gratings ruled with this engine are now supplied to physicists all over the world.

By means of a spectroscope properly arranged with suitable accessories, the Sun's spectrum has been both delineated and photographed alongside of the spectra of numerous terrestrial substances. Foremost among recent investigators in this field, and in mapping the solar spectrum, are Thollon in France, Lockyer and Higgs in England, Thalén in Sweden, Smyth in Scotland, and in America Rowland, Young, Trowbridge and Hutchins. Their research, together with that of previous investigators, principally Kirchhoff and Angström, Vogel and Fievez, has led to the certain detection of at least 35 elemental substances in the Sun, among which are:

(Al) Aluminium.	(Ag) Silver.
(Ba) Barium.	(C) Carbon.
(Cd) Cadmium.	(Ca) Calcium.
(Co) Cobalt.	(Cu) Copper.
(Cr) Chromium.	(Fe) Iron.
(H) Hydrogen.	(Mg) Magnesium.
(Mn) Manganese.	(Ni) Nickel.
(Na) Sodium.	(Si) Silicon.
(Sc) Scandium.	(Ti) Titanium.
(V) Vanadium.	(Zn) Zinc.

Hydrogen, iron, nickel, titanium, calcium and manganese are the most strongly marked. All the oxygen lines of the solar spectrum are due to the oxygen of our atmosphere. Chlorine and nitrogen, so abundant on the Earth, and gold, mercury, phosphorus and sulphur, are as yet undiscovered. Also the solar spectrum appears to indicate the existence of many metals in the Sun not now recognized upon the Earth; but it must be remembered that our globe is known only

superficially, and there is every reason for believing that the Earth, if heated to incandescence, would afford a spectrum very like that of the Sun itself.

The chemical spectra of many metallic elements freed from impurities are not yet fully known, but these are in the process of thorough investigation by Rowland, and Kayser and Runge of Hanover. Their researches will make possible a more searching comparison with the solar spectrum, hundreds of the dark lines in which are due to absorption by the Earth's atmosphere, and are consequently called telluric lines. Especial studies of these have been made by MM. Janssen, Thollon and Cornu, Becker and McClean. Whether the solar spectrum is constant in character is not known; with a view to the determination of this question in the future, Professor Piazzi Smyth conducted a series of observations for fixing the absolute spectrum in the year 1884. Mr. Higgs, of Liverpool, studying those strikingly marked bands in the solar spectrum due to the absorption by oxygen in our atmosphere, and known as '*great B*' and 'great A,' finds that the double lines are in rythmic groups, in harmonious sequence, capable of representation by a simple geometric construction.

Regarding the solar spectrum (prismatic) as a band of color merely, the maximum intensity of heat rays falls just below the red (at some distance inferior to the dark Fraunhofer line A); and that of light falls in the yellow (between *D* and *E*); and that of chemical or photographic activity, in the violet (between G and H); but in the normal spectrum these three maxima are brought more closely together, approaching the middle of the spectrum, which nearly coincides with the yellow D lines of sodium.

Beyond the red in the solar spectrum is a vast region wholly invisible to the human eye; but modern physicists have devised methods for mapping it with certainty. Sir John Herschel, J. W. Draper and Becquerel were the pioneers in this research, the last utilizing various phosphorescent substances upon which an intense spectrum had been projected for a long time. Direct photographic maps of the infra-red regions are very difficult, because the actinic intensity is exceeding feeble; and Abney, by means of collodion plates specially prepared with bromide of silver, has made an extended catalogue of the invisible dark bands. But Professor Langley has pushed the mapping of the infra-red spectrum to an unexpected limit by means of the bolometer, a marvellously sensitive energy-measurer of his own invention. In order to understand in outline the operation of the bolometer, or spectro-bolometer, it is necessary to recall that, as the temperature of a metal rises, it becomes a poorer conductor of electricity; as it falls its conductivity increases, iron at 300° below centigrade zero being, as Professor Dewar has shown, nearly as perfect an electrical conductor as copper. The characteristic feature of the bolometer is a minute strip of platinum leaf, looking much like an exceedingly fine hair or coarse spider web. It is about $\frac{1}{4}$ inch long, $\frac{1}{100}$ inch broad, and so thin that a pile of 25,000 strips would be only an inch high. This bolometer film, then, having been connected into a galvanometer circuit, is placed in the solar spectrum formed either by a grating or through the agency of rock salt prisms; and as it is carried along the region of the infra-red, parallel to the Fraunhofer lines, the fluctuations of the needle may be accurately recorded.

In this manner he first represented the Sun's invisible heat spectrum in an energy-curve; but his recent application of an ingenious automatic method, accessory to the bolometer, has enabled him to photograph its indications in a form precisely compar-

able with the normal spectrum. Bolography is the name given by Professor Langley to these processes which, by the joint use of the bolometer and photography, have automatically produced a complete chart of the invisible heat spectrum equal in length to ten times the entire luminous spectrum of the Sun, though indications of heat extend still farther. A fuller account of Professor Langley's significant work will be found in *Nature*, Vol. 51, (1894), p. 12, and in the new *Astrophysical Journal* for February, 1895, published at the University of Chicago. The bolometer was built by Grunow of New York, and forms part of the equipment of the astrophysical observatory of the Smithsonian Institution at Washington. So sensitive is this delicate instrument that it is competent to detect a temperature fluctuation as minute as the millionth part of a degree centigrade. It is proper to add that the researches conducted with such an instrument, often appearing remote and meaningless to a layman, are eminently practical in their bearing, as they pertain directly to the way in which the Sun affects the Earth, and man in his relations to it; and to the method of distribution of solar heat, forming thus, among other things, a scientific basis for meteorology.

At the end of the solar spectrum remote from the red is the ultra-violet region, ordinarily invisible; a portion of which may, however, be seen by receiving it upon uranium glass or other fluorescent substances. Glass being nearly opaque to the short wave-lengths of violet and ultra-violet, the optical parts of instruments for this research are made of quartz or calc-spar, or the necessary dispersion is obtained by using the diffraction grating. The superior intensity of the chemical or actinic rays in this region renders photography of especial service; and sensitive films stained with various dyes have been effectively employed. The painstaking investigations of Rutherfurd, Cornu, H. Draper, Rowland and Vogel have provided splendid maps of the invisible ultra-violet spectrum, exceeding many times the length of the visible spectrum. The farther region of the ultra-violet is pretty abruptly cut off by the absorptive action of our atmosphere.

The constant of solar heat, first investigated by Herschel and Pouillet in 1837–38, was redetermined by Professor Langley in 1881. He adopts *three calories* (small) as the solar constant, which signifies that "at the Earth's mean distance, in the absence of its absorbing atmosphere, the solar rays would raise one gramme of water three degrees centigrade per minute for each normally exposed square centimetre of its surface. * * * Expressed in terms of melting ice, it implies a solar radiation capable of melting an ice-shell 54.45 metres deep annually over the whole surface of the Earth." Professor Langley's *Researches on Solar Heat and its Absorption by the Earth's Atmosphere; A Report of the Mount Whitney Expedition*, were published as No. xv. *of the Professional Papers of the Signal Service* (Washington, 1884).

To express the solar heat in terms of energy: When the Sun is overhead, each square metre of the Earth's surface receives (deducting for atmospheric absorption) an amount of heat equivalent to $1\frac{1}{2}$ horse-power continuously. In solar engines like those of Ericsson and Mouchot about $\frac{7}{8}$ of this is virtually wasted. Of heat radiation emitted from the Sun and passing along its radius, Professor Frost finds that about $\frac{1}{4}$ part is absorbed in the solar atmosphere, which, were it removed, would allow the Earth to receive from the Sun 1.7 times the present amount. Imagine the hemisphere of our globe turned towards the Sun to be covered with horses, arranged as closely together as possible, no horse standing in the shadow of any other; then cover the opposite hemisphere with an equal number of horses: the solar energy intercepted by the

Earth is more than equivalent to the power of all these animals exerting themselves to the utmost and continuously.

It is easy to show that "the amount of heat emitted in a minute by a square metre of the Sun's surface is about 46,000 times as great as that received by a square metre at the Earth, * * * that is, over 100,000 horse-power per square metre acting continuously." * * * (Young.) If the Sun were solid coal this rate of expenditure would imply its entire combustion in about 6,000 years. The effective temperature of the Sun's surface is difficult to determine, and has been variously evaluated, from the enormously high estimates of Secchi, Ericsson and Zöllner, to the more moderate figures of Spoerer and Lane, who deduced temperatures of 80,000° to 50,000° Fahrenheit. According to Rosetti, it is no less than 18,000° Fahrenheit, an estimate probably not far wrong. M. Le Chatelier, however, in 1892, found the temperature a little short of 14,000°, and Wilson and Gray about 12,000°. Dr. Scheiner's recent observations upon the peculiar behavior of two lines in the spectrum of magnesium confirm these lower values in a remarkable way, apparently showing that the Sun's temperature lies between that of the electric arc (about 6,000°) and that of the electric spark (probably as high as 20,000°). A still later value is 40,000° C., derived by Herr Ebert of Kiel in 1895, by a method, however, involving much theoretic uncertainty.

The maintenance of this stupendous outlay of solar energy is explainable on the theory advanced by Von Helmholtz in 1856, who calculated that an annual contraction of 250 feet in the Sun's diameter will account for its entire radiation in a year—a rate of shrinkage so slow that many centuries must elapse before it will become detectable with our best instruments. Accepting this theory, Lord Kelvin estimates that the Earth cannot have been receiving the Sun's light and heat longer than 20,000,000 years in the past; and Professor Newcomb calculates that in 5,000,000 years the Sun will have contracted to one-half of its present diameter, and it is unlikely that it can continue to radiate sufficient heat to maintain life of types now present on the Earth longer than 10,000,000 years in the future. But it is now known that there are elements neglected in this computation which render a revision necessary and will probably extend this time very greatly. Assuming that solar heat is radiated uniformly in all directions, computation shows that all the known planets receive almost a two-hundred-millionth part of the entire heat given out by the Sun, the Earth's share being about $\frac{1}{10}$ of this. The vast remainder seems to us essentially wasted, and its ultimate destination is unknown.

To epitomize Professor Young's statement of the theory of the Sun's constitution, generally accepted:

(a) The Sun is made up of concentric layers or shells, its main body or nucleus being very probably composed of gases, but under conditions very unlike any laboratory state with which we are acquainted, on account of the intense heat and the extreme compression by the enormous force of solar gravity. These gases would be denser than water, and viscous, in consistency possibly resembling tar or pitch.

(b) Surrounding the main body of the Sun is a shell of incandescent clouds, formed by condensation of the vapors which are exposed to the cold of space, and called the photosphere. Telescopic scrutiny shows that the photosphere is composed of myriad 'granules' about 500 miles in diameter, excessively brilliant, and apparently floating in a darker medium.

(c) The shallow, vapor-laden atmosphere in which the photospheric clouds appear to float is called the 'reversing layer,' because

its selective absorption produces the Fraunhofer lines in the solar spectrum. It probably is somewhat less than 1,000 miles in thickness. The reversing layer contains a considerable quantity of those vapors which have given rise to the brilliant clouds of the photosphere, just as the terrestrial atmosphere adjacent to clouds is itself saturated with the vapor of water.

(d) The chromosphere and prominences are permanent gases, mainly hydrogen and helium, mingled with the vapors of the reversing layer but rising to far greater elevations than the vapors do. Jets of incandescent hydrogen appear to ascend between the photospheric clouds, much like flames playing over a coal fire. Calcium vapor is the most intensely marked of all the metals in the solar spectrum, even more so than of iron, which has over 2,000 line-coincidences, while calcium has only about 80.

(e) Still above photosphere and prominences is the corona, hitherto observable only during total eclipses, and extending to elevations far greater than any truly solar atmosphere possibly could. The characteristic green line of its spectrum, due to a substance not yet discovered on the Earth, and hence called 'coronium,' is brightest close to the Sun's limb, and during the eclipse of 1st January, 1889, it was traced outward by Professor Keeler to a distance of 325,000 miles. But much of the coronal light is known to originate in something other than the gaseous incandescence of hydrogen and coronium, because of the dark lines seen to cross its spectrum. These indicate solar light, reflected probably from small meteoric particles, possibly the debris of comets, circulating about the Sun in orbits of their own.

Dr. Huggins and Dr. Schuster maintain the view that the coronal streamers are in part due to electric discharges. The corona appears to be a very complex phenomenon, and as yet it is only in part understood. Two rival theories are now prominent; Mr. Schaeberle's mechanical theory (*Lick Observatory Reports on the Total Eclipse, 22d December, 1889*), and Professor Bigelow's theory (*The Solar Corona discussed by Spherical Harmonics*, Washington, 1889), that the coronal light is merely a phenomenon of the Sun's magnetism. But neither of these theories has yet been shown competent to undergo the ultimate test—that of predicting the general configuration of the coronal streamers at future eclipses.

Among modern solar theories may be mentioned that of Schmidt (1891), an optical theory of the solar disk, making the Sun wholly gaseous, in fact, a planetary nebula, existing in space without a definite outline anywhere, as we see it; so that the photosphere would be an apparent or optical surface merely, and not a real or natural one, such as the Sun's disk and limb seem actually to be in the telescope. The best English exposition of Schmidt's theory is that of Herr Wilczynski of Berlin, in the February (1895) number of the *Astrophysical Journal;* followed in the same issue by Professor Keeler's clear statement of certain practical objections to this theory. If Schmidt's theory were true, it is exceedingly improbable that the Sun's apparent or angular diameter would remain practically a constant quantity, as we know it does. Also may be mentioned the theory of the Sun by Dr. Brester of Delft, published in 1892, and characterized by much novelty. Rejecting the hypothesis of eruptional translation of solar matter, he conceives the Sun to be a relatively tranquil gaseous body, of essentially the same elementary composition as our Earth; and he attempts to show, in accordance with well known properties of matter, that the same cause which would keep the mass in repose must produce also 'chemical luminescence,' as he terms it. Great material eruptions, then, are merely deceptive appearances, be-

ing simply moving flashes in tranquil incandescent gases. Neither of these theories, however, is accepted to any great extent by practical students of the Sun and observers of solar phenomena.

The surface of the Sun (photosphere, spots, faculæ and prominences) is now a subject of daily study at many observatories, particularly at Potsdam, Meudon, Rome, and the Kenwood Observatory of the University of Chicago, where Professor Hale has instituted many significant innovations, in which he has been closely followed by M. Deslandres, of Paris; and observations are rapidly accumulating, the complete discussion of which ought soon to settle many points in the solar theory now disputed. But as the Sun's corona is visible only a few hours in a century, our knowledge of that object makes haste very slowly, and must continue to do so, unless the photographic method of Dr. Huggins (apparently successful in 1883, though later not), or of other investigators, shall make it possible to study the brighter streamers of the corona without an eclipse. Results of a patient series of recent attempts, however, are not encouraging. But it is well worth noting that an application of Professor Langley's bolometer, lately proposed by Professor Hale, though not yet put into execution, may still enable us to map the corona at any time by means of the minute variations in its heat from part to part. And many astronomers are hopeful that this ingenious suggestion may yet give a trustworthy outline picture of the corona in full sunlight, although the ability to picture it directly may forever be denied.

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CURRENT NOTES ON PHYSIOGRAPHY (XII.).

RECENT GEOGRAPHICAL SCHOOL BOOKS.

PROFESSOR SPENCER TROTTER'S 'Lessons in the New Geography' (Heath & Co., Boston, 1895) was referred to with approval in the Current Notes on Anthropology in SCIENCE for March 8th; but its geographical features are not altogether satisfactory. The spirit of the book is excellent. It does a good work in emphasizing the control that geographical conditions exercise over the distribution of plants, animals and man; but its physiographic foundation is not secure; the two brief chapters on the general forms of land and water and on climate and meteorology do not present the better modern views on these subjects; and the chapters on the geographical distribution of life, to which special attention is paid, do not satisfy the expectations of the biologist, as far as I have made inquiry. The faunal divisions recognized for America belong to the past; while the latest results, based on positive knowledge of the facts of distribution and of the facts of temperature control, are not mentioned. It is to be hoped that these deficiencies will be corrected in a later edition.

'Short Studies in Nature Knowledge,' an introduction to the science of physiography by William Gee, certified teacher of the education department (London, Macmillan, 1895), is one of a class of attractive books, whose object is to make geography better worth studying. Its entertaining chapters are well illustrated, if exception is made of certain exaggerated pictures, such as that of the Susquehanna, p. 121; but the book lacks a strong and scientific basis. The reader will probably be interested and attracted to further study; but he will not be impressed with the system and order of Nature's processes. As is so often the case, the impossible is attempted in giving an elementary explanation of the general circulation of the winds.

'A Brief Descriptive Geography of the Empire State,' by C. W. Bardeen (Bardeen, Syracuse, N. Y., 1895, 75 cents), is intended for local use, giving an account of the general topography, surface (mountains,